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RESULTS OF RAMJET FACILITY MODEL TESTS AT MACH 11

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July 1966

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FOREWORD

The work reported herein was done at the request of the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), under Program Element 62405214, Project 6951, Task 695101.

The results of the research presented were obtained by the FluidDyne Engineering Corporation under Contract AF40(600)-1132. The investigation was conducted from April 1965 to May 1966. The manuscript was submitted for publication on June 2, 1966. Mr. M. L. Laster (AERP) served as the Air Force program monitor for the research effort.

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This technical report has been reviewed and is approved.

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ABSTRACT

A test program has been conducted to provide ramjet test facility bypass flow second throat diffuser pressure recovery data at a nominal nozzle exit Mach number of 11.0. During the tests, studies were made to determine the effects of Reynolds number, diffuser throat length, inlet capture, area, and other variables.

The pressure recoveries obtained during the testing proved to be somewhat better than the original expectations. The peak running pressure recovery was over 60% of free stream normal shock recovery with the adjustable diffuser. Starting pressure recoveries were somewhat lower and ranged mostly from 20% to 30% of normal shock.

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LIST OF SYMBOLS

A	Area
A^*	Throat area (general)
A_{core}	Facility nozzle exit potential flow core area
$A_{effective}$	Effective area
A_i	Ramjet inlet geometric capture area
A_i^*	Ramjet inlet throat area
A_N	Facility nozzle geometric exit area
A_{NE}	Facility nozzle effective exit area
A_{NT}	Facility nozzle throat area
A_S	Scavenging scoop frontal area
A_{ST}	Bypass flow diffuser second throat area
K_1	Constant in empirical equation for minimum starting second throat area
K_2	Constant in empirical equation for minimum running second throat area

l	Distance along nozzle from throat
M	Mach number
M_{nozzle}	Nozzle exit Mach number
$M_{\text{ST ideal}}$	Ideal diffuser second throat Mach number
P	Pressure
P_t	Stagnation pressure
P_{t0}	Upstream nozzle stagnation pressure
P_{t1}	Stagnation pressure immediately upstream of shock wave
P_{t2}	Stagnation pressure downstream of shock wave
T	Temperature
T_{exh}	Bypass diffuser outlet stagnation temperature
T_o	Nozzle stagnation temperature
T_{wall}	Nozzle and diffuser wall temperature
Re	Reynolds number
δ	Boundary layer thickness
δ^*	Boundary layer displacement thickness
η	Efficiency
η_{NS}	Normal shock efficiency
η_p	Corrected efficiency
λ	Pressure ratio - P_{t0}/P_{t2}
λ_{MIN}	Minimum running pressure ratio across bypass diffuser
θ_c	Cowl flare angle

1.0 INTRODUCTION

In a free-jet ramjet test facility, the pressure recovery in the flow which bypasses the engine influences the size and cost of the exhausters required. Furthermore, it is important from a cost standpoint that the smallest possible facility be built for the engine to be tested. Consequently, the facility designer must have an accurate knowledge of the attainable bypass flow second throat diffuser pressure recovery and be able to select the maximum permissible or optimum inlet-to-nozzle exit area ratio.

References 1 through 10 contain second throat diffuser pressure recovery data for Mach numbers up to 7.0. In the current program, bypass diffuser pressure recovery data were obtained at a nominal Mach of 11.0 because of the need for full scale hypersonic testing of scramjet engines at such a Mach number.

Since hypersonic ramjet engines may be relatively short and could have short cowls, it becomes practical to simulate the external flow field over the entire engine rather than just simulating the inlet flow field. This being practical, it appeared mandatory to consider a facility configuration in which the inlet was completely independent of the bypass diffuser rather than forming a part of it. Consequently, the current facility model contains an engine exhaust scavenging scoop and the entire inlet and engine is modeled.

Two inlet-engine combinations were built for this contract; one corresponding to $A_i/A_N = .225$, and the other, smaller, model to $A_i/A_N = .156$. In addition, two scavenging scoop diameters were provided; one for the large engine model, and the other for the small engine model. Tests were conducted with and without the engine models installed. For one test, the capture

area of the scavenging scoop was completely filled with a large spike. The complete test program is outlined in Table 1.

2.0 APPARATUS

In order to provide the experimental data required under the subject contract, ramjet test facility models were designed, built and tested at Fluidyne Engineering Corporation. These models and the support facilities used during the tests are described below.

2.1 GENERAL FACILITY DESCRIPTION

The AEDC, second throat diffuser tests were conducted at Fluidyne Engineering Corporation's Medicine Lake Laboratory. This laboratory contains what is known as the Fluidyne Hypersonic Flight Simulation Facility. Among the facility components used for these diffuser tests were the 500 psi and the 5000 psi air supplies, the zirconia storage heater, and the vacuum system (Figure 1).

The 5000 psi air supply was used to provide the primary AEDC facility model air flow. This air is stored in a 60 cu. ft. tank which is recharged between runs. A run time of approximately 50 seconds was attainable at $P_0 = 1500$ psi. The facility model air flow was heated to the desired temperature by passing it through the zirconia pebble bed storage heater. Air temperatures as high as 3000°R were used. The facility model exhaust flow was run into a vacuum tank to provide adequate overall pressure ratio.

The facility model consisting of Mach 11 nozzle, engine model, bypass flow diffuser, etc., was attached to the pebble bed heater air outlet. Figure 2 shows the layout of the test setup. Photos of the test setup and engine models appear in Figure 3. The individual facility model components are discussed in detail in the following subsections.

2.2 THE MACH 11 NOZZLE

The nozzle used to produce flow for the facility model test is the same flow generating nozzle as is customarily used in conjunction with Fluidyne's hyper-sonic wind tunnel. The nozzle was originally designed to produce $M = 14$ flow at $P_t = 2000$ psi and $T_o = 4000^\circ R$. Coordinates computed by WADC using the Cresci method for a source flow half angle of 8° were used for the nozzle potential flow contour. The nozzle was subsequently provided with an enlarged throat making it possible to obtain good quality flow at a lower hyper-sonic Mach number (between 11.0 and 12.0, depending on the total pressure and temperature). A typical nozzle calibration obtained at $P_{t_o} = 1050$ psi and $T_o = 3250^\circ R$ appears as Figure 4. The nominal Mach number of 11.0 corresponds to an effective-to-geometric area ratio of $A_{NE}/A_N = 0.68$ while the ratio of potential flow core area-to-nozzle geometric area is 0.275. During the current testing at $2000^\circ R$ stagnation temperature, the indicated Mach number was 11.3 so the proper effective-to-geometric area ratio for the tests is 0.65.

2.3 THE INLET AND ENGINE MODEL

To minimize facility size and exhaust capacity requirements, it is desirable to make the facility nozzle exit diameter as small as possible relative to the engine size contemplated at the expense of facility pressure recovery. For Mach numbers in the hypersonic regime, it is the nozzle potential flow core diameter which limits the engine size-to-nozzle geometric area ratio. This diameter can be estimated by making an

empirical calculation of the nozzle exit boundary layer thickness using the following equation

$$\frac{\delta}{L} = \frac{0.8}{Re^{0.8}} \quad (2.1)$$

where L is the nozzle length and Re is the Reynolds number per foot at the nozzle exit multiplied by the nozzle length. In the current situation, the potential flow core diameter was known to be 10.5 inches and an inlet capture area of 80% of the core area was selected as being as large as practical. Two engine models were built, one with the maximum practical inlet capture area of 71 sq. in. and a second with a capture area of 49 sq. in.

Because of the desirability of directly measuring engine thrust in the full scale facility, the inlet model shrouds were not designed to be part of the bypass diffuser while in the testing reported in Reference 10 an extension of the inlet cowling formed the inner wall of the bypass diffuser annulus. The complete inlet-engine combinations were modeled and mounted independently of the diffuser between the nozzle exit and the diffuser pickup (Figure 2). This necessitated the inclusion of an exhaust scavenging scoop plus an air injection system incorporated in the engine model to simulate the volume flow increase due to heat addition so that the capturing of the exhaust plume could be studied. The secondary air supply system was sized to permit unstarting of the inlet. The spikes have a constant cone angle of 12.5° . The internal contraction was limited to 0.75 to insure inlet starting since there were no means provided to mechanically vary the inlet

contraction ratio. An overall contraction ratio of 0.23 resulted. The design of the inlet-engine combinations was selected on the basis of References 11 through 22 and by customer directives. A photo of the inlet-engine models appears in Figure 3. The models were enclosed by the hypersonic wind tunnel test cabin and windows in the test cabin permitted schlieren viewing of the inlet and exhaust flow field.

Under the total pressure, total temperature, and Mach number condition required for these tests, it was not necessary to cool the inlet-engine models. The models were built from mild steel.

2.4 THE BYPASS FLOW SECOND THROAT DIFFUSER

The bypass flow diffuser system consisted of a 12-inch nominal diameter engine exhaust scavenging scoop and a surrounding annular-adjustable bypass flow second throat diffuser. Second throat diffuser area variation was provided by a fixed outer cone shell and an axially adjustable central cone which rode on the O.D. of the scavenging scoop pipe. This is essentially the same method of area adjustment used in Reference 10. For the current design, both the inner and outer cone angles were 10° . A length of essentially constant effective diffuser throat area was formed between the inner and outer cones to provide efficient deceleration to subsonic flow. Additional throat length was provided by an inner cone extension. The variation of diffuser throat length-to-annulus height ratio with inner cone axial location is shown in Figure 5.

A double ended air cylinder with 35 inches of piston travel was used to drive the inner cone. The

outer (free) end of the piston rod was ruled to give a direct indication of diffuser inner cone position which could then be directly related to diffuser throat area (Figure 6). Details of the general diffuser design appear in Figure 2. Figure 3 contains photographs of the diffuser and components.

Two inlet-engine models and corresponding scavenging scoops were designed to study the effect of engine size; a twelve inch inside diameter scoop size used with the larger engine model, and a 10 inch I.D. size obtainable by installing a conical ring insert in the upstream end of the 12 inch scoop (see Figure 2). Tests were made with the engine models removed leaving only the scavenging scoop. In addition, a configuration was tested which consisted of a center spike only with no capture area.

On the basis of extensive $M = 11$ testing in the hypersonic tunnel, it was considered safe to eliminate water cooling of the diffuser components because the heat flux was low enough so that the structure was an adequate heat sink.

2.5 THE FACILITY EXHAUST SYSTEM

The flow from the scavenging scoop and that from the bypass flow diffuser were mixed in a 26 inch I.D. exhaust tube before passing through the hypersonic wind tunnel after-cooler into the 33,500 cu. ft. vacuum sphere. It was anticipated that the ejector action of the relatively high energy flow from the scavenging scoop pipe exit would help to pump the lower energy bypass flow.

2.6 INSTRUMENTATION

In addition to the stagnation pressure and temperature measuring location, pressure taps were located at strategic points on the nozzle, inlet and engine model, and bypass flow diffuser so that the flow process could be readily interpreted. Figures 2 and 7 show the location of most of the measuring points. Table 2 contains a list of the measurements made, the instrument used to make the measurement, and the stated accuracy of the instrument. In almost all cases, transducers giving an electrical output were used as the measuring instruments. Their outputs were recorded on 18 channel, Consolidated Electrodynamics recorders which use light beam galvanometers with light sensitive chart paper.

A sensitive double pass schlieren optical system designed and built by FluidDyne for flow visualization in the hypersonic tunnel, was used to study the inlet and engine exhaust flow field. It could be observed if the facility nozzle was started, if the inlet was started, and how well the engine model exhaust was being captured by the scavenging scoop.

3.0 TEST PROCEDURE

3.1 RUN PROCEDURE

Several kinds of information were desired from the testing and a number of different run procedures were devised to get this information with a minimum of runs. The testing primarily involved the determination of minimum starting throat areas, minimum running throat areas and starting and running pressure ratio requirements. Regardless of the configuration, these tests usually began by finding the minimum starting diffuser throat area and the minimum running pressure ratio near the starting area setting. This was accomplished by bringing the tunnel stagnation conditions up to the desired running value and then opening up the diffuser throat until the facility flow reached the "started" condition. At this point the vacuum valve was closed so as to backpressure the diffuser and get the pressure ratio at which flow broke down.

The next test sequence provided the starting pressure ratio as well as the minimum running diffuser throat area, which was obtained by closing the diffuser throat until the flow unstated. The third test sequence gave a check on the starting pressure ratio and the running pressure ratio at a diffuser setting near the minimum running position. For this third sequence the facility model was started, the diffuser throat closed to a reasonable running value, and the downstream vacuum valve closed to cause unstart.

A fourth procedure was used to see if it would be possible to operate the facility with the engine inlet in a subcritical condition. For all of the tests with

the engine model installed, combustion was simulated by adding air to the captured flow inside of the model. Placing blockage downstream of the air injection station within the model made it possible to unstart the inlet (cause subcritical operation) by adding sufficient air and this was done for one of the tests.

3.2 BETWEEN RUN ACTIVITIES AND DATA REDUCTION

Between runs, the vacuum tank was pumped down, the air supply tanks were pumped up, the heater bed temperature brought back up to the required prerun value and calibration of the pressure transducers was accomplished. Calibration consisted of applying known pressures to the transducers and measuring the recorder trace deflection. The time between runs was also used to plot up the calibrations (pressure versus trace deflection) and to reduce the data from preceding runs. Data reduction involved reading out manometer photographs and using the calibrations to read pressures and temperatures off the recorder chart. From inspection of the recorder chart for a particular run, it was usually possible to tell immediately if and when starting and unstarting of the facility nozzle and inlet took place during the run. The points read out were those corresponding to start or unstart. The pressure data were used to determine overall pressure ratio requirements, inlet recovery, and local pressures.

4.0 DATA CORRELATION METHODS

The methods of correlating the data for the current test program will be essentially the same as those introduced in Reference 10. The development of the methods is discussed in Section 4.0 of Reference 10 and is included in this report as an appendix. In the following subsections, the various correlation equations are reviewed.

4.1 DIFFUSER EFFICIENCY

In addition to presenting the inverse of the pressure recovery directly as the ratio P_{t0}/P_{t2} , two definitions of diffuser efficiency will be used. The first of these is the customary normal shock efficiency, η_{NS} , where the actual pressure recovery is compared to the pressure recovery across a normal shock at the undisturbed free stream Mach number.

$$\eta_{NS} = \frac{(P_{t2}/P_{t0})_{\text{actual}}}{(P_{t2}/P_{t1})_{NS @ M_{\text{nozzle}}}} \quad (4.1)$$

The second definition of diffuser efficiency was developed in Reference 10 and is referred to as the corrected efficiency, η_p . In this definition, the actual pressure recovery is compared to the pressure recovery across a normal shock at the ideal diffuser throat Mach number, $M_{ST_{\text{ideal}}}$. The equation corresponding to this definition is presented here in slightly different form than it was in Reference 10 since it is the scavenging scoop area, A_S , rather than the engine inlet area A_i ,

which determines how much of the total flow remains to go through the bypass flow second throat diffuser.

$$\eta_p = 0.618 (P_{t2}/P_{t0})_{\text{actual}} \left(\frac{A_N}{A_{NT}} \right) \left(\frac{A_{NE}}{A_N} \right) \frac{\left(1 - \frac{A_S}{A_N} \right)}{\left(\frac{A_{NE}}{A_N} - \frac{A_S}{A_N} \right)} \left(\frac{A_{ST}}{A_N - A_S} \right)$$

for $(5.0 \leq M \leq \infty)$ (4.2)

This definition of efficiency accounts for tunnel geometry, boundary layer growth, etc., so that η_p remains reasonably constant over a wide range of geometries and test conditions. For wind tunnels having adequate diffuser throat lengths $\eta_p = 0.80$ is typical while for ramjet test facility diffusers, the value is somewhat lower at $\eta_p \approx 0.60$.

4.2 THE MINIMUM STARTING SECOND THROAT AREA

In order to correlate minimum starting throat area data, a correlation constant K_1 was defined in Reference 10 such that K_1 was the ratio of the actual minimum starting second throat area to the ideal minimum starting throat area based on one-dimensional flow. The equation defining K_1 is

$$K_1 = \frac{\left(\frac{A_{ST}}{A_N - A_S} \right)_{\text{min start}} \left(1 - \frac{A_S}{A_N} \right)}{0.62 - \left(\frac{A_{i*} + A_S - A_i}{A_N} \right)} \quad (4.3)$$

As in Equation 4.2, the quantities included in the above equation are slightly different from those as presented in Reference 10, that is, A_S is used in place of the inlet area A_i .

4.3 THE MINIMUM RUNNING SECOND THROAT AREA

The minimum running second throat area for an adjustable diffuser is limited by the onset of boundary layer separation in the throat region. The occurrence of separation is related to the relative boundary layer displacement thickness and the strength of disturbances originating near the diffuser entrance. In Reference 10, a correlation equation was developed which accounted for these factors and yielded an empirical coefficient K_2 which hopefully would be a constant which could be applied to predict minimum running second throat for untested situations. This correlation equation is

$$K_2 = \frac{\left(\frac{A_{ST}}{A_N - A_{S \text{ min run}}} \right) \left[\left(\frac{A_N}{A_{NT}} \right) \left(\frac{A_{NE}}{A_N} \right) \right]^{0.6} \left(1 - \frac{A_S}{A_N} \right)}{\left[\frac{(P_2/P_1)_{\theta_c}}{(P_2/P_1)_{\text{sep}}} + 1 \right] \left(1 - \frac{A_{NE}}{A_N} \right)} \quad (4.4)$$

The ratio $(P_2/P_1)_{\theta_c}/(P_2/P_1)_{\text{sep}}$, which relates the pressure rise produced by the diffuser entrance disturbance with that required for separation, is plotted as a function of Mach number in Figure 8.

The correlation of wind tunnel and ramjet facility data presented in Reference 10 resulted in an average K_2 of 16.0. Inclusion of the test results reported in Reference 11 resulted in a K_2 of 17.5 for closed jet or closed gap facilities and 22.0 for open jet or open gap facilities.

5.0 RESULTS AND DISCUSSION

5.1 GENERAL

The bypass flow second throat diffuser pressure recoveries, normal shock efficiencies, and corrected efficiencies are plotted in Figures 9, 10, and 11. An overall pressure ratio of $\lambda = 1040$ represents the best performance attainable with either engine model installed. This corresponds to a normal shock efficiency of approximately 59%. Figures 9, 10, and 11 also show minimum starting and minimum running diffuser throat areas. Final correlations of starting and running throat data appear as Figures 12 and 13.

Figures 14 and 15 present local pressure data and bypass diffuser pressure distribution data. The diffuser pressure distributions are plotted for a number of diffuser backpressure situations up to near unstart.

Schlieren photos of the started inlet and the exhaust flow field are shown in Figure 16. On the basis of a pitot probe on the inlet spike tip, the free stream Mach number during all tests averaged 11.3.

Most of the testing was accomplished with a stagnation pressure of 1500 psi and a stagnation temperature of 2000°R.

5.2 DIFFUSER PERFORMANCE

Starting and running pressure ratios and throat areas come under the heading of diffuser performance. This subsection contains a discussion of the influence of a variety of geometric and aerodynamic variables on diffuser performance.

5.2.1 Starting Pressure Ratio and Throat Area

The major geometric change applied during the tests involved removal of the engine-inlet model and the substitution of a spike centerbody to cover the end of the 5 inch air supply-engine model support tube. Results obtained with the engine model installed will be discussed first.

5.2.1.1 Large Engine Model Installed

Starting, with the engine model installed, was accomplished with no engine injection air since the actual facility would be started before engine ignition took place. By raising the facility model stagnation pressure to the running level and then opening the diffuser throat (Run 3), it was found that the starting second throat area ratio for this configuration is $A_{ST}/(A_N - A_S) = 0.90$ as shown in Figure 9. This is 31% higher than the theoretical value or, i.e., $K_1 = 1.31$. K_1 values for all configurations are presented in Figure 12.

At a diffuser area ratio setting of 0.97, the starting pressure ratio across the bypass diffuser was found to be 3500 for the large engine configuration (Runs 4 and 5) which corresponds to a starting recovery of only 18% or normal shock recovery. Apparently, the scavenging scoop removes most of the flow during the starting process and starves the bypass diffuser (a phenomenon described on Page 30 of Reference 10). However, when the scavenging scoop "steals" most of the flow, the ejector action where the scoop and bypass flows are remixed is improved. Consequently, the overall starting pressure ratio between stagnation pressure and mixing tube exit was only 2160 corresponding to 29% of normal shock starting recovery.

The basic configuration described above consisted of the shorter of the two bypass diffuser throats (see Figure 5 for characteristics) and had an extension on the bypass diffuser pickup. Test results from the short and long diffuser throat configurations revealed no difference in either starting or running performance between the two (Runs 3 through 8) so the short configuration alone was used for the engine-out tests and the tests with a reduced size engine model. The diffuser cone could probably have been shortened to 80% of the shortest length tested without reducing the pressure recovery because, under the running conditions, the length to hydraulic diameter ratio of the constant area throat was about 25% longer than ordinarily required for adequately efficient shockdown.

One run was made with the diffuser scoop extension removed. The overall starting pressure ratio and bypass diffuser pressure ratio both equalled 3301 for only 19% of normal shock starting pressure recovery. The remainder of the testing was done with the scoop extension in place.

5.2.1.2 Small Engine Model Installed

With the reduced size engine model and scavenging scoop, the facility model started with $A_{ST}/(A_N - A_S) = 0.725$ which corresponds to $K_1 = 1.10$ (Run 19). The starting pressure ratio across the bypass diffuser at a diffuser setting of 0.80 was 2700 while the overall pressure ratio was only 2000 (Runs 20 and 21). These pressure recovery values correspond to normal shock efficiencies of 23% and 31%, respectively.

5.2.1.3 Engine Model Out

The initial tests with the engine out were conducted

with the 5 inch engine-model support tube capped over by a small diameter spike. With this spike, both the large scavenging scoop configuration and the reduced scavenging scoop configuration failed to start consistently; in fact, only the reduced size scoop configuration started at all, and this happened only once in three attempts. It was felt that "bypass diffuser starvation" was again a factor, so the spikes covering the 5 inch support tube were enlarged to make the scavenging scoop into a reasonably efficient inlet with a small throat and thereby increase spillage during the starting process. These designs are shown in Figure 2.

With the revised spikes, the engine out configurations could be started consistently. The starting throat areas were the same as they were with the engines installed, namely: $A_{ST}/(A_N - A_S) = 0.90$ for the large scoop and 0.73 for the small scoop (Runs 12 and 15). These values correspond to K_1 values of 1.13 and 1.02, respectively. The starting pressure ratio across the bypass diffuser with the large scoop size (Run 13) was very high (4850) at $A_{ST}/(A_N - A_S) = 1.0$, indicating that the "starvation" problem associated with the original failure to start was not entirely avoided by adding the larger spike. Again, this resulted in improved ejector performance in the mixing tube so that the overall starting pressure ratio was only 2360 (27% of normal shock starting recovery). At $A_{ST}/(A_N - A_S) = 0.80$ (Run 16), a bypass diffuser starting pressure ratio of only 2160 was required for the reduced size scavenging scoop which indicated no "starvation". There was no appreciable difference

between this and the overall pressure ratio so both gave starting pressure recoveries corresponding to 29% of normal shock.

At the end of the test program, the downstream end of the scavenging scoop was instrumented and a special run (Run 22) was made with this configuration to determine the primary flow conditions entering the downstream mixing tube. Of special interest was the starting situation when a large share of the total flow passes through the scavenging scoop. During both starting and running the static to pitot pressure at the scoop pipe exit was approximately equal to .20 which corresponds to an exit Mach number of 1.70.

5.2.2 Running Pressure Ratio and Throat Area

5.2.2.1 Large Engine Model Installed

All of the engine model-installed running diffuser performance data were obtained with air injection in the model to simulate the volume increase due to combustion and the resulting exhaust plume. A schlieren photo showing the exhaust flow field appears in Figure 16. The amount of air injected corresponded to about doubling the stagnation enthalpy of the engine flow. With the injection air on (Runs 4 and 7) the minimum running diffuser throat area ratio turned out to be $A_{ST}/(A_N - A_S) = 0.38$. This corresponds to a K_2 value of 29.9 in contrast to a value of 22.0 suggested in Reference 10 for open jet or open gap configurations. During one run, the minimum running area ratio was obtained with no injection air and was found to be 0.30 ($K_2 = 23.0$). This indicated that the exhaust plume has the effect of causing some of the free stream

flow to spill into the bypass diffuser; that this is true is borne out later in a comparison between the running pressure ratios with the engine model in and those obtained with it removed. Apparently, the spreading of the exhaust plume causes the flow over the inlet cowl to separate from the surface. This deflects it radially into the bypass diffuser. During the test program the minimum running diffuser throat area was found at a significantly reduced test Reynolds number ($P_0 = 500$ psi, $T_0 = 3000^\circ\text{R}$ instead of the customary $P_0 = 1500$ psi, $T_0 = 2000^\circ\text{R}$). The permissible contraction was affected significantly since the throat area could only be reduced to $A_{ST}/(A_N - A_S) = 0.49$ (Run 10). Whether this was due to an increase in facility nozzle boundary layer thickness or to the influence of Reynolds number on cowl boundary layer separation on the engine model is uncertain.

A minimum running pressure ratio point was always obtained near, but not at, the minimum running bypass diffuser throat setting. With the engine model in and the throat set at $A_{ST}/(A_N - A_S) = 0.49$, a pressure ratio of approximately 1200 was required to maintain flow (Runs 5 and 8). This corresponds to a normal shock efficiency of 53%. At a diffuser setting of $A_{ST}/(A_N - A_S) = 0.97$ (Runs 3 and 6), the required pressure ratio was 1850 ($\eta_{NS} = 34\%$). For all of the running pressure ratio data, the overall pressure ratio and bypass diffuser pressure ratio were essentially equal since the mass flow ratio between the scoop and diffuser did not result in significant ejector action on mixing.

The average corrected efficiency for the data is

65% as shown in Figure 11. As mentioned in 5.2.1.1, the diffuser throat constant area length had no effect on either minimum throat areas or pressure recoveries. At reduced Reynolds number, the running pressure ratio required was only slightly higher than normal for the throat setting involved (Run 11).

5.2.2.2 Small Engine Model Installed

With the small engine model installed (Runs 19, 20, and 21), the minimum running throat area was sensitive to the quantity of air injected to simulate combustion when that quantity exceeded a certain amount. The permissible contraction, $A_{ST}/(A_N - A_S)$, varied from 0.30 to 0.60 with only a small increase in injection air flow. Only the minimum value was used in the correlation shown in Figure 13.

The minimum running pressure ratios with the small engine were slightly lower than those obtained with the large engine model. This is probably due to the increase in potential flow through the bypass diffuser at a given throat setting. At a throat setting of $A_{ST}/(A_N - A_S) = 0.45$ the running pressure ratio was 1050 which corresponds to a normal shock efficiency of 0.60. The corrected efficiency, η_p , averaged 58% for this configuration.

5.2.2.3 Engine Model Out

Removal of the engine model eliminated the influence of the exhaust plume on minimum running pressure ratio and minimum running diffuser throat area. For the larger, basic, scoop size the running pressure ratio was 1100 at $A_{ST}/(A_N - A_S) = 0.50$ with the engine model installed. Removal of the engine model increased the

minimum running pressure ratio to 1500, which corresponds to a normal shock efficiency of 0.42.

With the engine removed and the smaller scavenging scoop size the running pressure ratios were somewhat improved over the basic scoop performance at a given diffuser setting because more flow was going through the bypass diffuser. At $A_{ST}/(A_N - A_S) = 0.50$ (Run 17), for example, the required running pressure ratio for the smaller scoop size was 1320 as opposed to 1500 for the larger, basic scoop design. A pressure ratio of 1590 was required at a diffuser throat area ratio of 0.86. The corrected efficiencies for both scavenging scoop configurations averaged about 52% which is somewhat lower than was obtained during the $M = 7$ testing reported in Reference 10.

The presence or absence of the engine model and exhaust plume did not have a consistent effect on the minimum running diffuser throat area. Ordinarily one would expect the exhaust plume to limit the permissible contraction, but with the small scavenging scoop the minimum running throat area was smaller with the engine model installed and the exhaust plume being simulated (see Figure 9). With the larger scoop the trend was as expected with the minimum running throat area $A_{ST}/(A_N - A_S)$, being equal to 0.39 with the model installed and equal to 0.35 with the engine model removed (Runs 7 and 13).

5.2.3 Tests with 100% Bypass Flow (Centerbody Diffuser)

An attempt was made in Run 18 to get pressure recovery and diffuser contraction data on what amounted to a zero size engine and scavenging scoop configuration

(see Figure 2). Instead of the engine and scavenging scoop, this configuration had a spike centerbody which drove all of the flow into the bypass diffuser. A started condition could not be obtained in the two attempts allotted to this configuration. The inability to obtain a start is not understood since the available overall pressure ratio of $\lambda = 1900$ and available $A_{ST}/(A_N - A_S) = 0.80$ would ordinarily be adequate.

5.3 LIMIT OF SUBCRITICAL OPERATION

By a slight modification of the engine model internal geometry, it was possible to add enough injection air to unstart the inlet, that is, to cause subcritical operation. During one test (Run 9) this was done purposely to see if the facility model would remain started with the inlet terminal shock expelled. From the recorder traces, it was clear that no stable subcritical operation was attained. Although there was a short finite time interval between the instant of shock expulsion and unstart, this was probably due to the large test cabin volume which had to be filled before nozzle flow breakdown occurred.

5.4 HEAT TRANSFER TO THE DIFFUSER WALLS

In Reference 10, a constant related to the total temperature drop in the air going through the nozzle and the bypass diffuser was defined such that

$$\frac{T_o - T_{exh}}{T_o - T_{wall}} = K_3 \frac{1 - A_{NE}/A_N}{1 - A_{S(i)}/A_N} \quad (5.1)$$

From the $M = 7$ tests, K_3 appeared to be equal to approximately 1.90. In the currently reported tests, however, K_3 appeared to vary between 1.30 and 1.50.

6.0 EMPIRICAL EQUATIONS FOR PREDICTING DIFFUSER PERFORMANCE

Except for the empirical factors relating starting pressure recoveries to running values, the empirical equations presented in Section 6.0 of Reference 10 for predicting diffuser performance were reasonably well substantiated by the $M = 11$ test results. The major change involves the corrected efficiency, η_p , which averages about 0.52 at $M = 11$ when there is no exhaust plume. A value of $\eta_p = 0.65$ was used in the equations presented in Reference 10. This required modification of the basic running pressure ratio equation for high Mach number ($M > 10$) testing to

$$\frac{P_{t2}}{P_{t0}} = \frac{0.84}{\left(\frac{A_N}{A_{NT}}\right)\left(\frac{A_{NE}}{A_N}\right) \left[\frac{1 - A_S/A_N}{\frac{A_{NE}}{A_N} - \frac{A_S}{A_N}} \right] \left(\frac{A_{ST}}{A_N - A_S} \right)} \quad (6.1)$$

The minimum starting diffuser throat area was found to be within 13% of the theoretically predicted value for the engine model out case which essentially verifies the open gap (open jet) results reported in Reference 10. With the engine model installed, the value of K_1 went up to 1.31. When the theoretical minimum starting throat area ratio equation is substituted into 6.1, an equation is obtained for predicting the best recovery attainable with a fixed bypass diffuser having no gap between the nozzle and diffuser.

$$\frac{P_{t2}}{P_{t0}} \text{ min run fixed diff} = \frac{0.84}{\left(\frac{A_N}{A_{NT}} \right) \left(\frac{A_{NE}}{A_N} \right) \left[\frac{0.62 - \left(\frac{A_S - A_i + A_i}{A_S} \right) \left(\frac{A_S}{A_N} \right)}{\frac{A_{NE}}{A_N} - \frac{A_S}{A_N}} \right]} \quad (6.2)$$

If there is a gap between the nozzle exit and diffuser shroud, the pressure recovery should be divided by 1.13 if the engine model is out and by 1.31 if the engine model is installed.

With the engine out, or with the engine installed and no air injection (combustion), or with the exhaust enclosed, the minimum running diffuser throat area can be estimated by using the following equation for the no gap case. The result should be multiplied by 1.57 for the open gap case.

$$\left(\frac{A_{ST}}{A_N - A_S} \right) \text{ min run adjustable} = \frac{17.5 \left[\frac{(P_2/P_1)_{\theta_c} + 1}{(P_2/P_1)_{sep}} \right] \left(1 + \frac{A_{NE}}{A_N} \right)}{\left[\left(\frac{A_N}{A_{NT}} \right) \left(\frac{A_{NE}}{A_N} \right) \right]^{0.6} \left(1 - \frac{A_S}{A_N} \right)} \quad (6.3)$$

Multiply this by 1.75 if the engine is operating and the exhaust plume is exposed as it was in the current testing. See Figure 8 for the separation pressure rise ratio.

This, then, can be substituted into 6.1 to give a relationship for estimating running pressure recoveries with an adjustable diffuser and a closed gap (closed jet).

$$\frac{P_{t2}}{P_{t0}} \text{ min run adjustable} = \frac{0.048}{\left[\left(\frac{A_N}{A_{NT}} \right) \left(\frac{A_{NE}}{A_N} \right) \right]^{0.4} \left\{ \frac{\left[\frac{(P_2/P_1)_{\theta_c} + 1}{(P_2/P_1)_{sep}} \right] \left(1 + \frac{A_{NE}}{A_N} \right)}{A_{NE}/A_N - A_S/A_N} \right\}} \quad (6.4)$$

This again is for the closed gap case. For an open gap, divide this by 1.57 or 1.75, as the case may be, to account for the particular test situation which is applicable. With simulated combustion, the corrected efficiencies were closer to those found during the Phase 1 testing and the equations presented in Reference 10 provide a good estimate of performance.

The equations above correlate the data for the current test series. To provide a single set of equations covering a wide range of Mach numbers with reasonable accuracy, one can average the empirical constants used above with those presented in Reference 10.

7.0 CONCLUSIONS

1. The running corrected efficiency for the tests made with the engine model removed averaged 52% which is lower than the average of 60% obtained during the $M = 7$ tests reported in Reference 10.
2. With the large engine model installed and combustion simulated, the running corrected efficiency averaged 65% because the exhaust plume caused spillage of flow into the bypass diffuser, i.e., the actual bypass flow was greater than estimated.
3. With the reduced size engine model installed, the running corrected efficiency averaged 59%.
4. None of the diffuser performance parameters were influenced by the diffuser constant area length within the range tested.
5. Reynolds number appeared to have a significant effect on minimum running throat area (the higher the Re the more contraction was possible).
6. To insure consistent starting with the engine model removed, it was necessary to make the scavenging scoop into a reasonably efficient inlet with a spike and a fairly large contraction.
7. By mixing the bypass and scavenging scoop flows in an ejector downstream of the diffuser, it is possible, in some instances, to make the overall starting pressure ratio considerably lower than the pressure ratio across the bypass diffuser.
8. No stable operation was obtained with the inlet terminal shock expelled.

REFERENCES

1. Anderson, D. E., "The Effect of Engine Size on Free-Jet Test Cell Performance," AEDC TN-57-19, November 1957.
2. Anderson, D. E., "Performance of a Free-Jet Diffuser With Small Inlet and Throat Size," AEDC TN-57-20, November 1957.
3. Latvala, E. K., "Performance of a Scale Model Free-Jet Engine Test Installation Incorporating Diffusers With Square Outer Fairings," AEDC TN-58-100, February 1959.
4. Feldmann, Gafarian, and Bitondo, "Aerodynamic Research for the Design of Altitude Free-Jet Test Sections for Ramjet Test Facilities," North American Aviation Report AL-1265, May 1951.
5. Feldmann, "Aerodynamic Research for the Design of Altitude Free-Jet Test Facilities for the Investigation of Side Inlet Ramjets," North American Aviation Report AL-1428.
6. Hunczak, "An Investigation at Mach Numbers 2.98 and 2.18 of Axially Symmetric Free-Jet Diffusion with a Ramjet Engine," NACA RM E51L24, February 1952.
7. Herman, Thompson, and Melnik, "Theoretical and Experimental Investigation of a Supersonic Conical Inlet Model with Shroud Type Diffuser in a Free-Jet Tunnel," University of Minnesota, Rosemount Research Laboratory, Research Report 154, November 1958.
8. Grunnet, J. L., "Model Studies of the Free-Jet Altitude Test Facility for the G-38 (D-53) Engine," Report written under contract to Wright Aeronautical Division, Curtiss-Wright Corporation, April 1957.

9. Fasken, S. D., "Design of Ramjet Engine Ground Test Facilities," Institute of the Aeronautical Sciences Preprint No. 841, July 1958.
10. Grunnet, J. L., "Results of Ramjet Facility Model Tests at Mach 7," AEDC TDR-63-173, August 1963.
11. Kutschenreuter, "Force Balance Determination of Inlet Performance for Advanced Vehicle Applications to Orbital Velocities Using Internal Drag Measurements," WP-ASD-TDR-63-701, September 1963.
12. Franciscus, "Off-Design Performance of Hypersonic Supersonic Combustion Ramjets," AIAA Paper 64-248, June 1964.
13. Dugger, "Recent Advances in Ramjet Combustion," ARS Journal, Vol. 29, No. 11, November 1959, p. 819.
14. Ferri, "Supersonic Combustion Progress," Astronautics and Aeronautics, August 1964, p. 32.
15. Avery and Dugger, "Hypersonic Airbreathing Propulsion," Astronautics and Aeronautics, June 1964, p. 42.
16. Weber and MacKay, "An Analysis of Ramjet Engines Using Supersonic Combustion," NACA TN-4386, 1958.
17. Ferri, "Possible Directions of Future Research in Air Breathing Engines," Combustion and Propulsion, Fourth AGARD Colloquium, 1960, p. 3.
18. Dugger, "A Comparison of Hypersonic Ramjet Engines with Subsonic and Supersonic Combustion," Ibid, p. 84.
19. Weber, "A Survey of Hypersonic-Ramjet Concepts," ARS Preprint 875-59, June 1959.
20. Kutschenreuter and Balent, "Hypersonic Inlet Performance from Direct Force Measurement," Journal of Spacecraft and Rockets (AIAA), Vol. 2., No. 2, March-April 1965, p. 192.

21. Benson and Maslowe, "Bluntness and Boundary Layer Displacement Effects on Hypersonic Inlet Flow Fields," AIAA Paper 65-617, June 1965.
22. Karanian and Kepler, "Experimental Hypersonic Inlet Investigation with Application to Dual-Mode Scramjet," AIAA Paper 65-588, June 1965.

TABLE 1. BASIC RUN PROGRAM

(not complete or in same
chronological order as tests)

Run	Eng. Model	Bypass Diff. Length	Scav. Scoop Diam.	P _o psia	T _o °R	Run Description
1	Large	Long	12"	1500	2000	Shakedown
2	Large	Long	12"	1500	2000	Exhaust Simulation Air Supply Determination
3	Large	Long	12"	1500	2000	$[A_{ST}/(A_N - A_S)]_{start}, \lambda_{min}$
4	Large	Long	12"	1500	2000	$\lambda_{start}, [A_{ST}/(A_N - A_S)]_{min run}$
5	Large	Long	12"	1500	2000	$\lambda_{start}, \lambda_{min opt}$
6	Large	Short	12"	1500	2000	$[A_{ST}/(A_N - A_S)]_{start}, \lambda_{min}$
7	Large	Short	12"	1500	2000	$\lambda_{start}, [A_{ST}/(A_N - A_S)]_{min run}$
8	Large	Short	12"	1500	2000	$\lambda_{start}, \lambda_{min opt}$
9	Large	Optimum	12"	1500	2000	Limit of Subcritical Operation
10	Large	Optimum	12"	500	3000	$[A_{ST}/(A_N - A_S)]_{min run}$ at Low Re
11	Large	Optimum	12"	500	3000	$\lambda_{min opt}$ at Low Re
12	Out	Optimum	12"	1500	2000	$[A_{ST}/(A_N - A_S)]_{start}, \lambda_{min}$
13	Out	Optimum	12"	1500	2000	$\lambda_{start}, [A_{ST}/(A_N - A_S)]_{min run}$
14	Out	Optimum	12"	1500	2000	$\lambda_{start}, \lambda_{min opt}$
15	Out	Optimum	10"	1500	2000	$[A_{ST}/(A_N - A_S)]_{start}, \lambda_{min}$
16	Out	Optimum	10"	1500	2000	$\lambda_{start}, [A_{ST}/(A_N - A_S)]_{min run}$
17	Out	Optimum	10"	1500	2000	$\lambda_{start}, \lambda_{min opt}$
18	Out	Optimum	Spike Only	1500	2000	Wouldn't Start

Run	Eng. Model	Bypass Diff. Length	Scav. Scoop Diam.	P _o psia	T _o °R	Run Description
19	Small	Optimum	10"	1500	2000	$[A_{ST}/(A_N - A_S)]_{start}, \lambda_{min}$
20	Small	Optimum	10"	1500	2000	$\lambda_{start}, [A_{ST}/(A_N - A_S)]_{min run}$
21	Small	Optimum	10"	1500	2000	$\lambda_{start}, \lambda_{min opt}$
22	Out	Optimum	12"	1500	2000	Study of Flow Situation in Scavenging Scoop Exit

TABLE 2. BASIC INSTRUMENTATION

<u>Measurement</u>	<u>Instrument</u>	<u>Manufacturer</u>	<u>Range</u>	<u>Accuracy Within</u>
Nozzle stagn press	gauge	Helicoid	0-2000 psia	± 5 psi
Nozzle stagn temp	unshielded T-C			
Nozzle exit press	transducer	Hastings-Raydist	0-20 mmhga	$\pm 2\%$
Test cabin press	transducer	Hastings-Raydist	0-20 mmhga	$\pm 2\%$
Inlet spike pitot pressure	transducer	Statham	0-50 psia	$\pm .05$ psi
Inlet spike static pressure	transducer	Hastings-Raydist	0-20 mmhga	$\pm 2\%$
Inlet throat press	transducer	Statham	0-10 psia	$\pm 1/4\%$ of F.S.
Inlet recovery pressure	transducer	Consolidated Electro-dynamics	± 25 psid	$\pm 1/4\%$ of F.S.
Exhaust nozzle throat static pressure	transducer	Statham	0-50 psia	$\pm .05$ psi
Exhaust plug static pressure	transducer	Hastings-Raydist	0-20 mmgha	$\pm 2\%$
Injection air stagn pressure	gauge	ACCO	-30 hg-150 psig	± 2 psi
Diffuser entrance static pressure	transducer	Statham	± 1 psid	$\pm 2\%$
Diffuser throat static pressure	transducer	Hidyne	0 - 1/2 psia	$\pm 2\%$ of F.S.

<u>Measurement</u>	<u>Instrument</u>	<u>Manufacturer</u>	<u>Range</u>	<u>Accuracy Within</u>
Diffuser exit stagn pressure	transducer	Statham	0 - 5 psia	$\pm 1/4\%$ of F.S.
Diffuser exit stagn temp	shielded T-C	Rosemount Eng.	3000°R	$\pm 1\%$
Mixing tube exit stagn pressure	transducer	Consolidated Electro- dynamics	± 25 psid	$\pm 1/4\%$ of F.S.

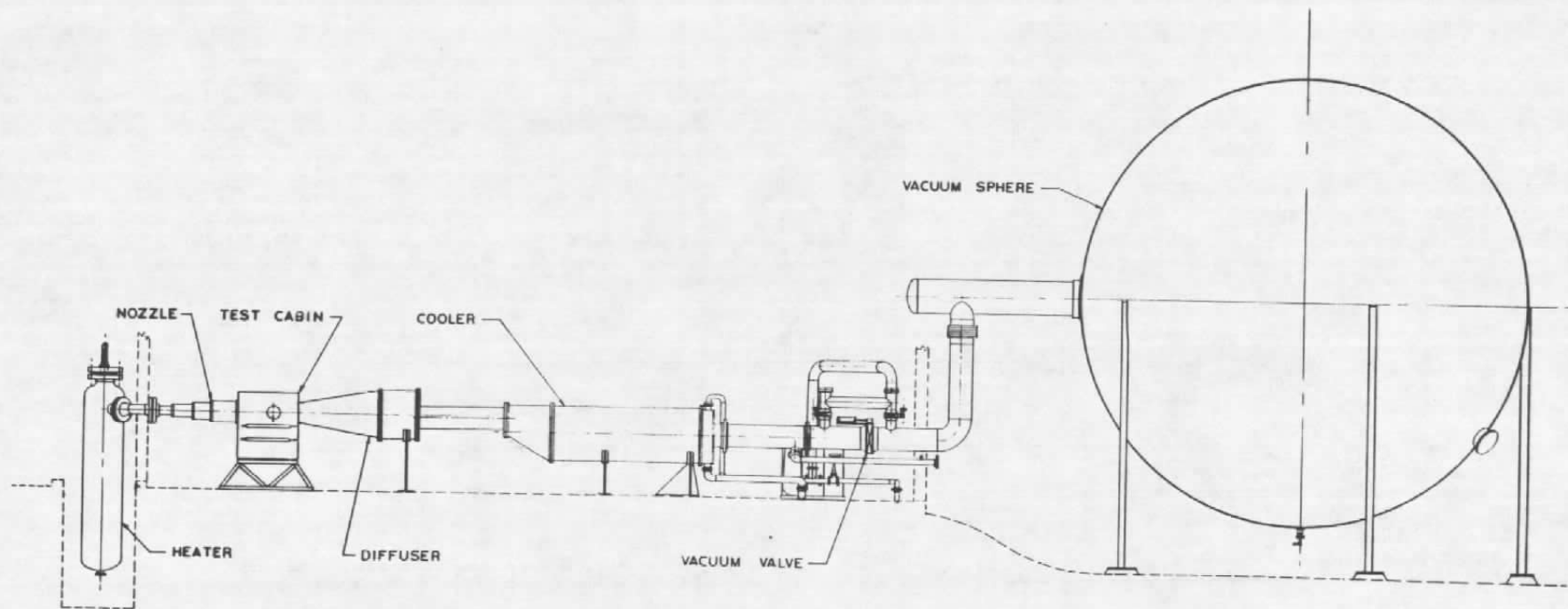


Fig. 1 Overall Layout of M = 11 Facility Model

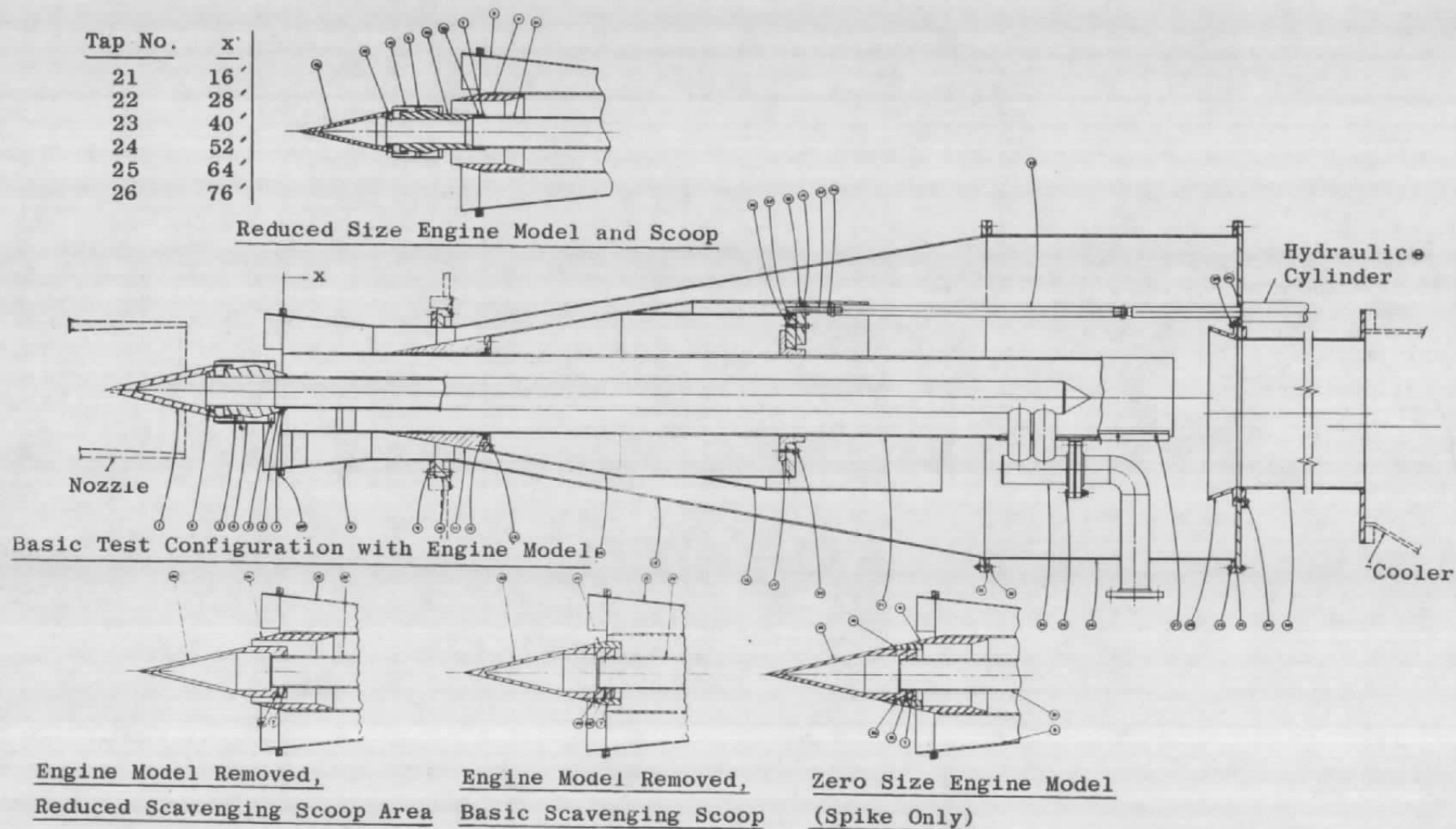
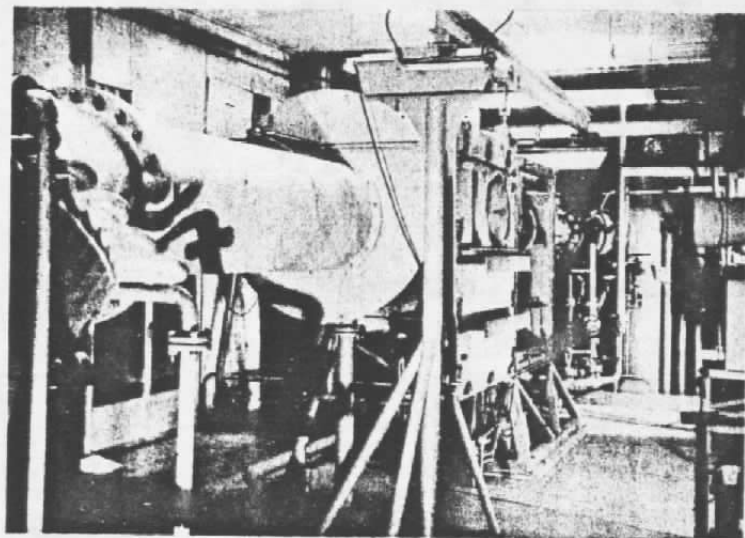
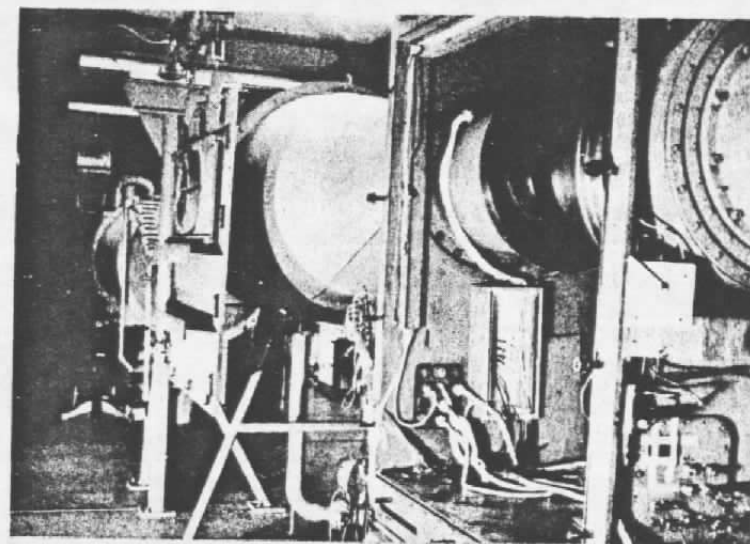


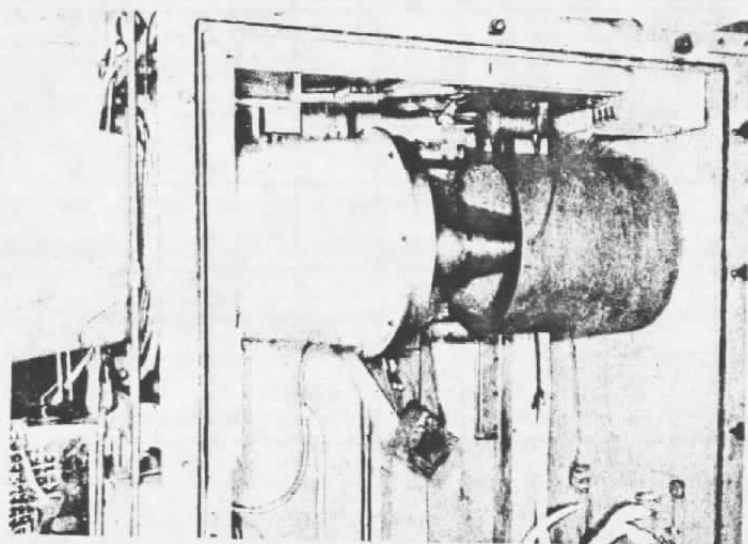
Fig. 2 Mach 11 Hypersonic Ramjet Test Facility Model



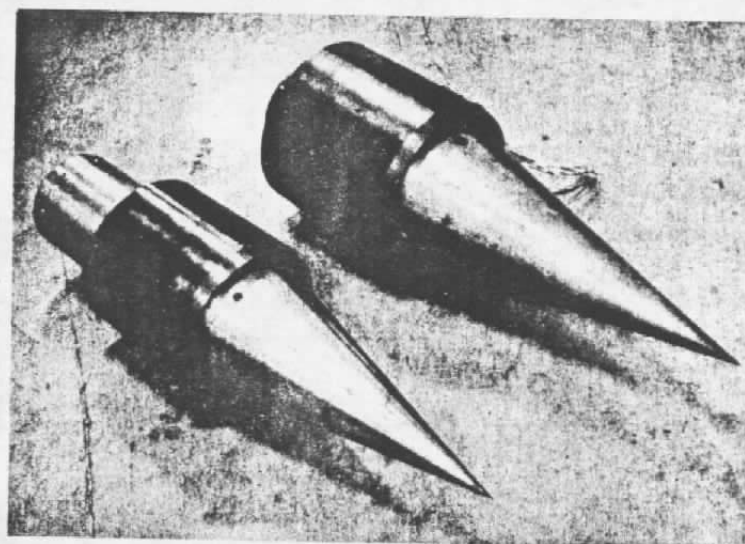
UPSTREAM VIEW



DOWNSTREAM VIEW



TEST SECTION



ENGINE MODELS

Fig. 3 Facility and Engine Model Photos

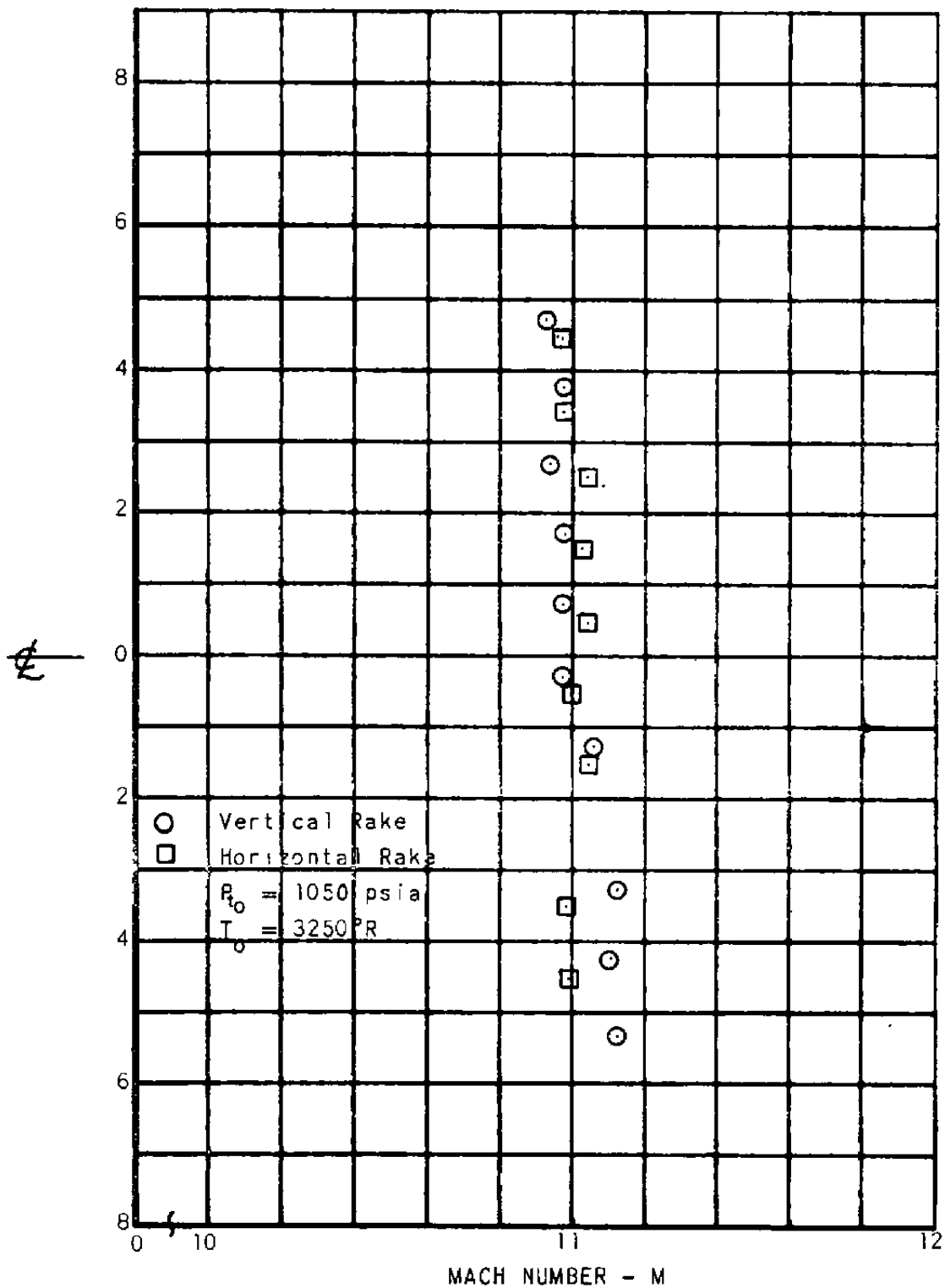


Fig. 4 Mach 11 Nozzle Calibration

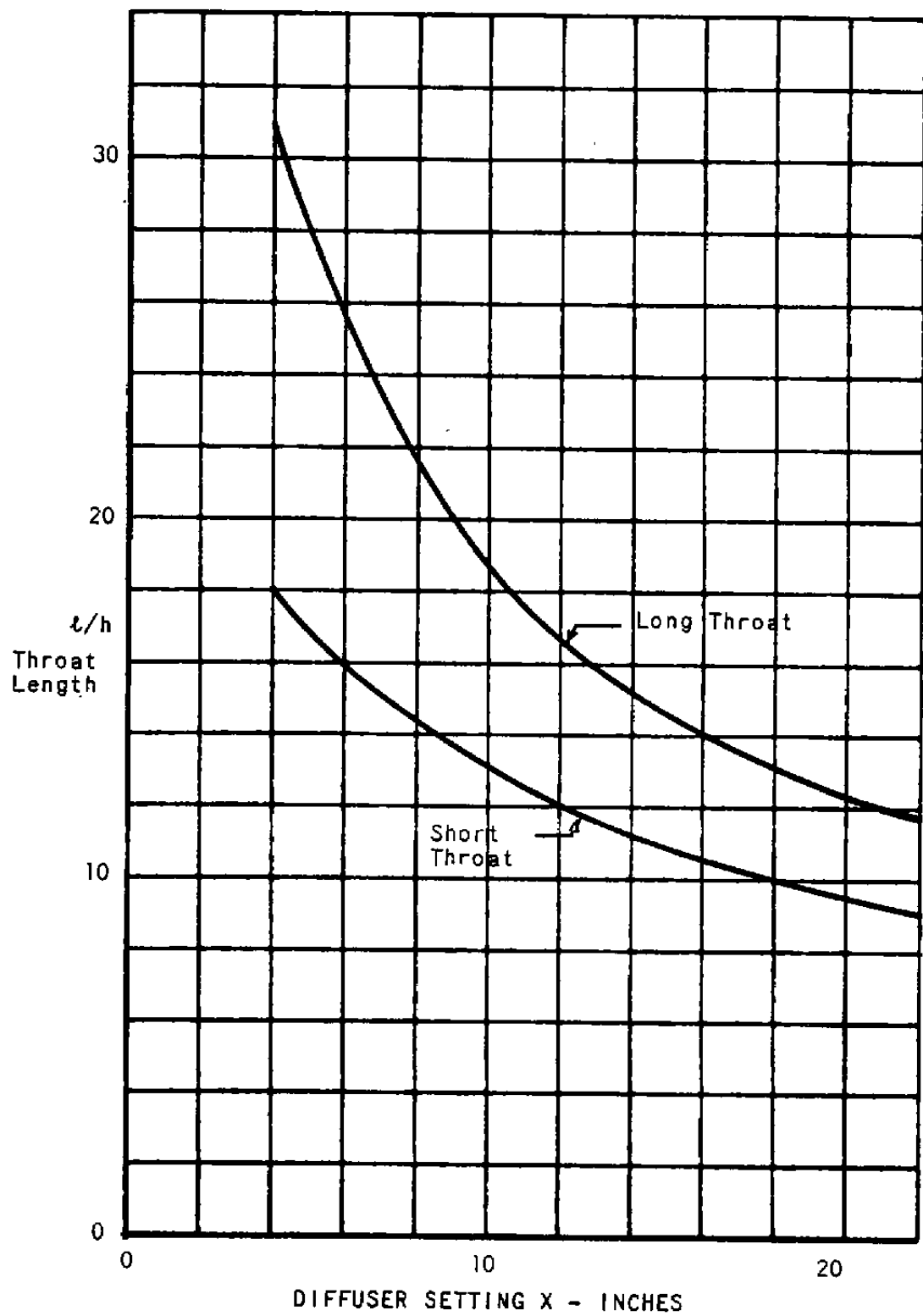


Fig. 5 Diffuser Throat Length to Annulus Height Ratio versus Diffuser Setting

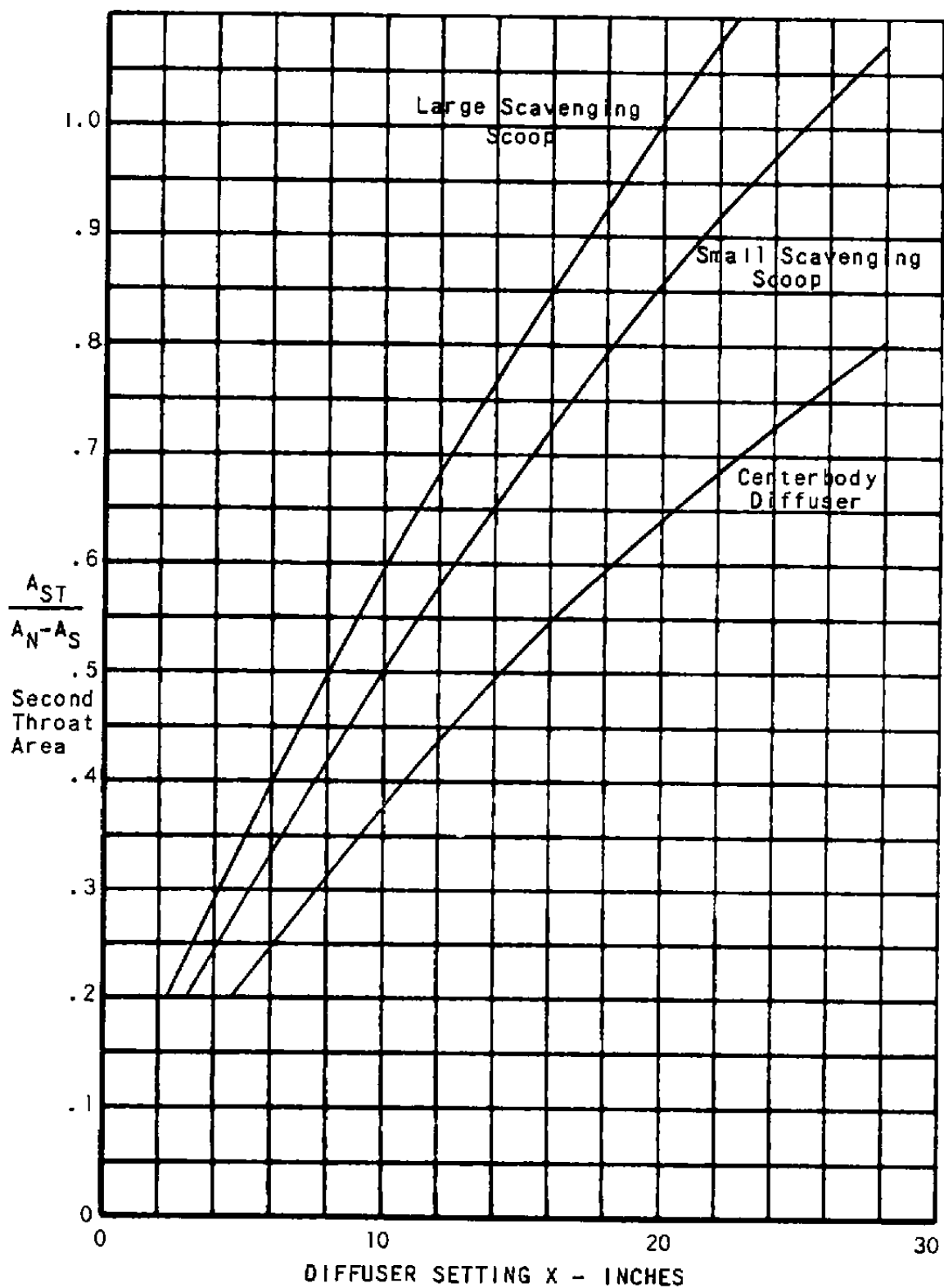
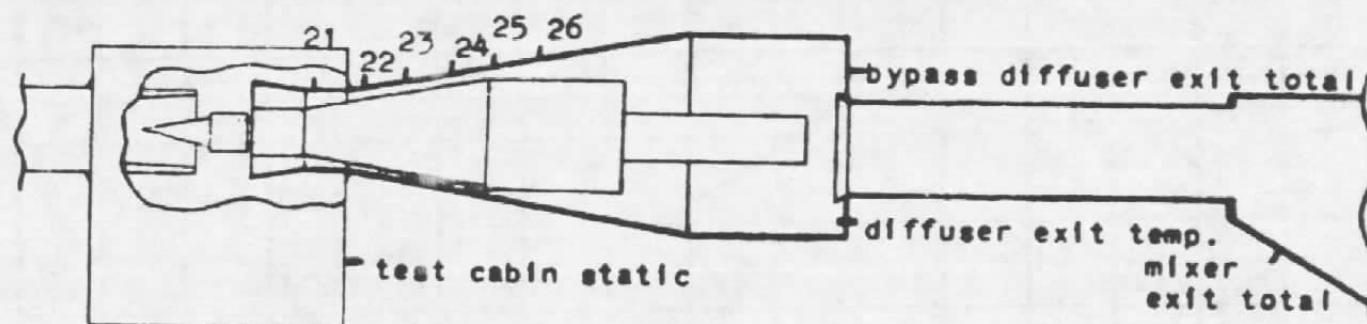
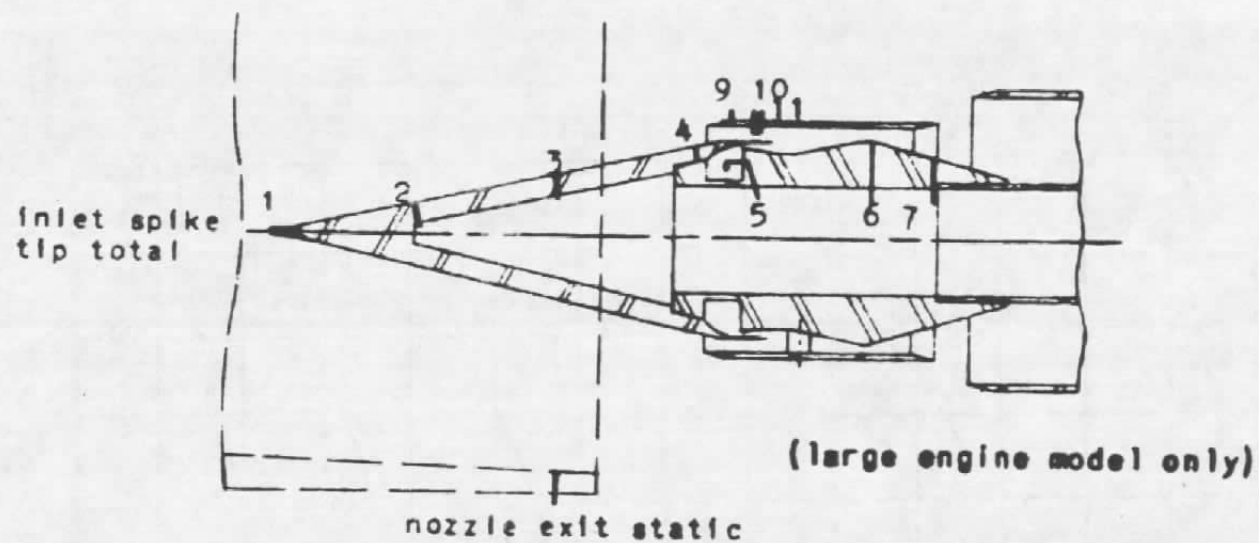


Fig. 6 Diffuser Throat Contraction versus Diffuser Setting



Tap No.	Description	Tap No.	Description
2,3,4	inlet spike statics	9,10	inlet throat statics
5	air injection total pressure	11	inlet throat pitot
6	exhaust throat statics	21-26	diffuser throat statics
7	exhaust plug statics		

Fig. 7 Location of Engine Model and Diffuser Instrumentation

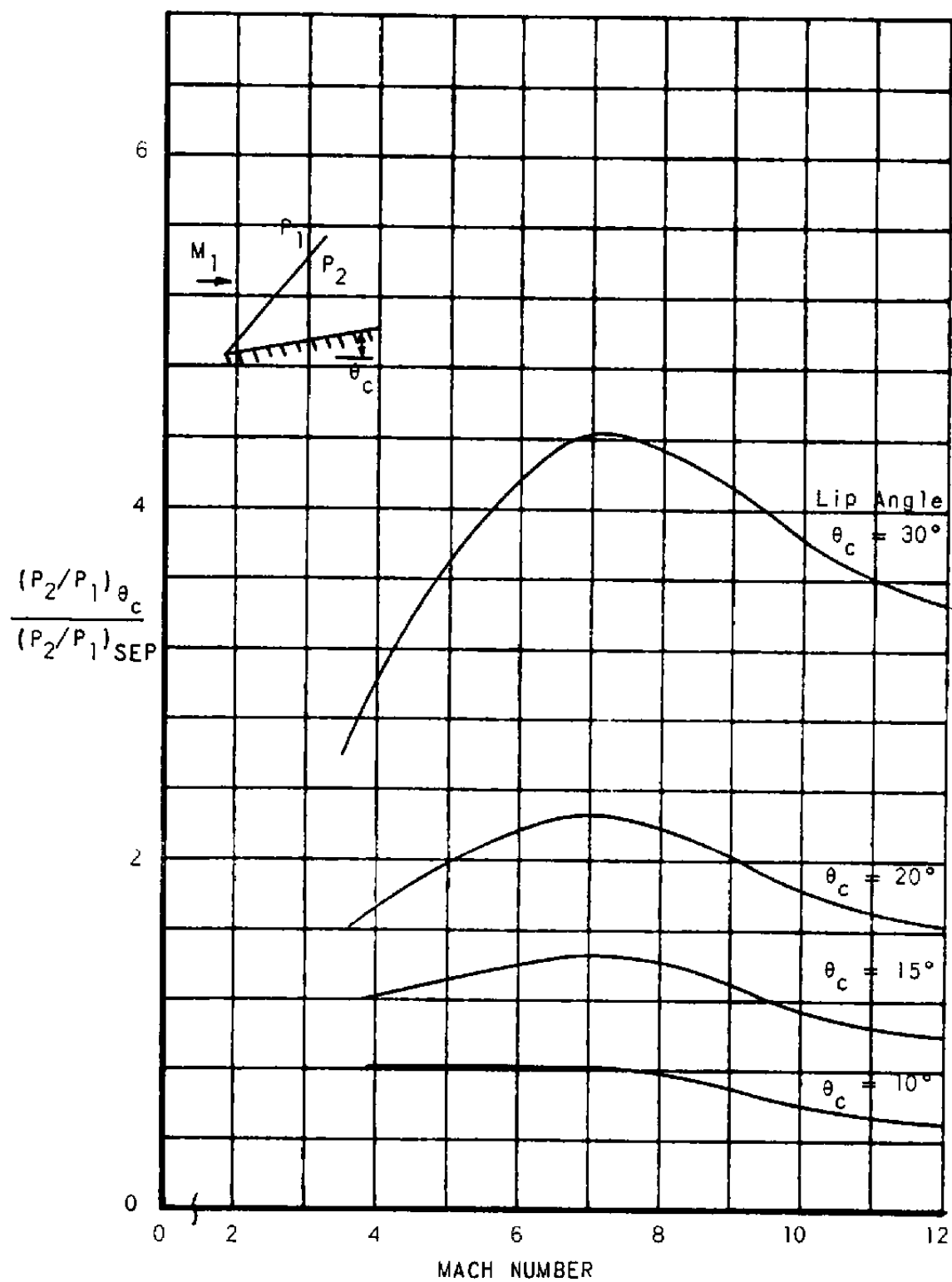


Fig. 8 Ratio of Separation Pressure Rise Ratio to Oblique Shock Pressure Rise Ratio for Turning Angle θ_c versus Mach Number

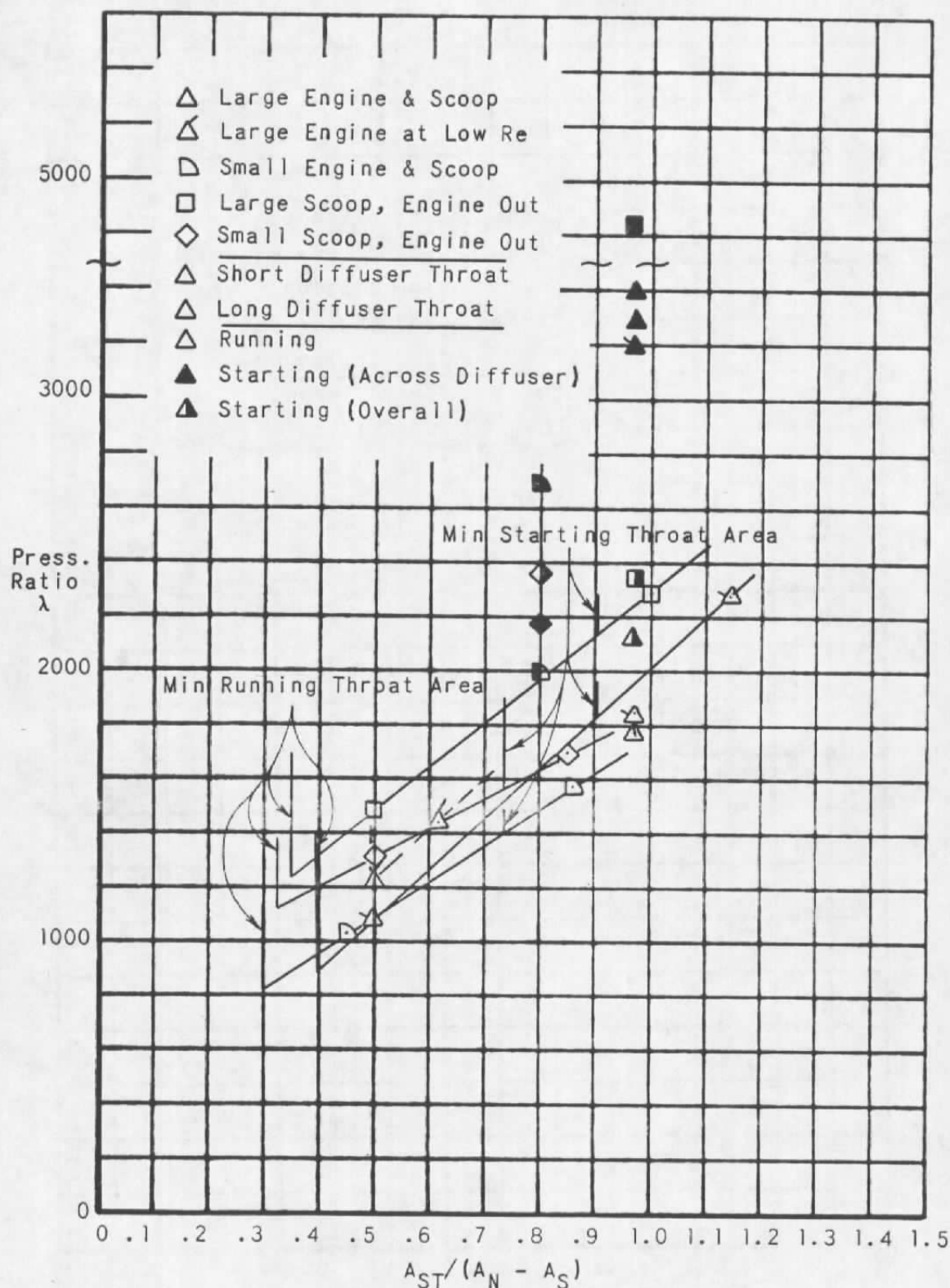


Fig. 9 Diffuser Starting and Operating Pressure Ratios versus Diffuser Throat Setting

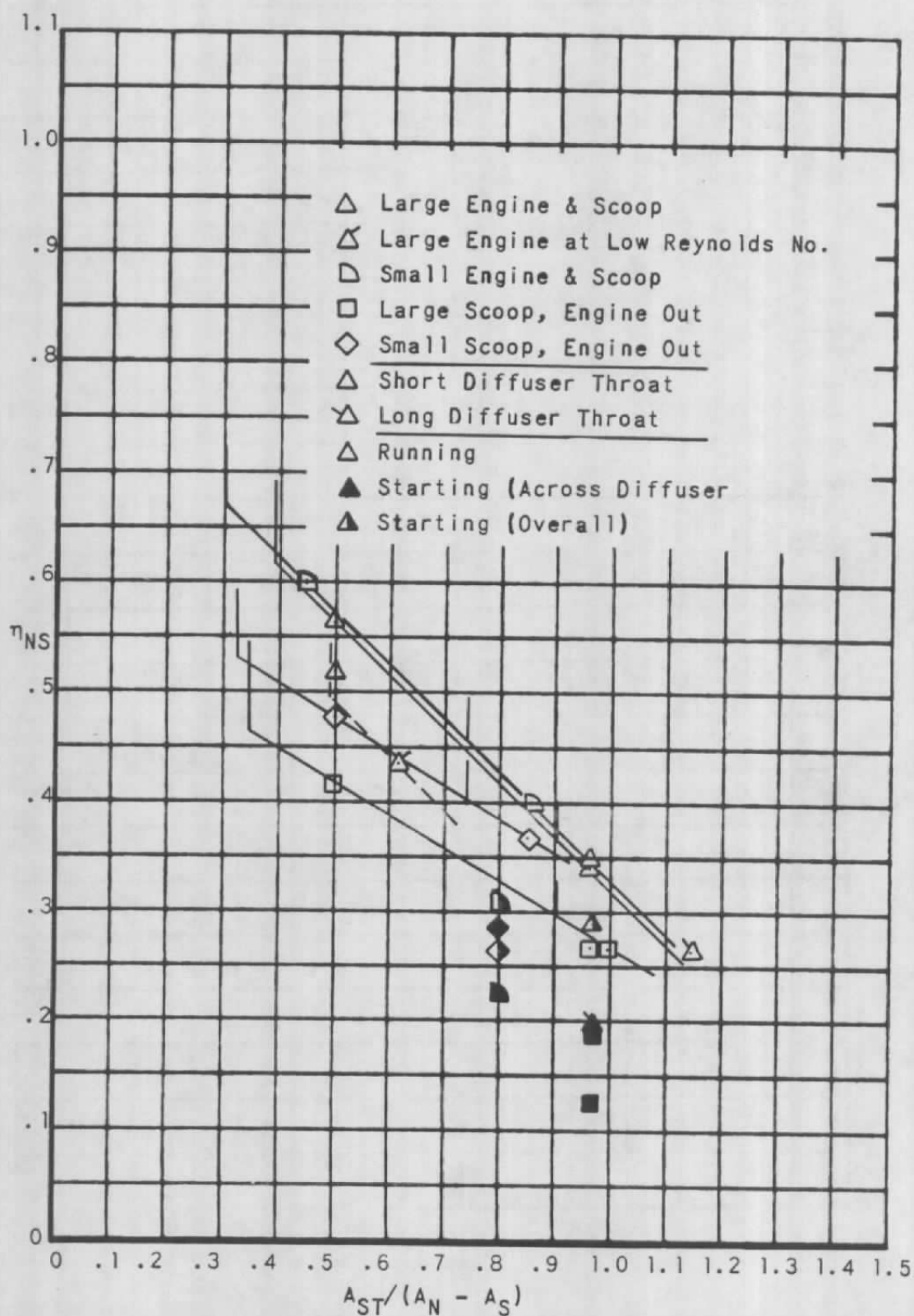


Fig. 10 Diffuser Normal Shock Efficiency versus Diffuser Throat Setting

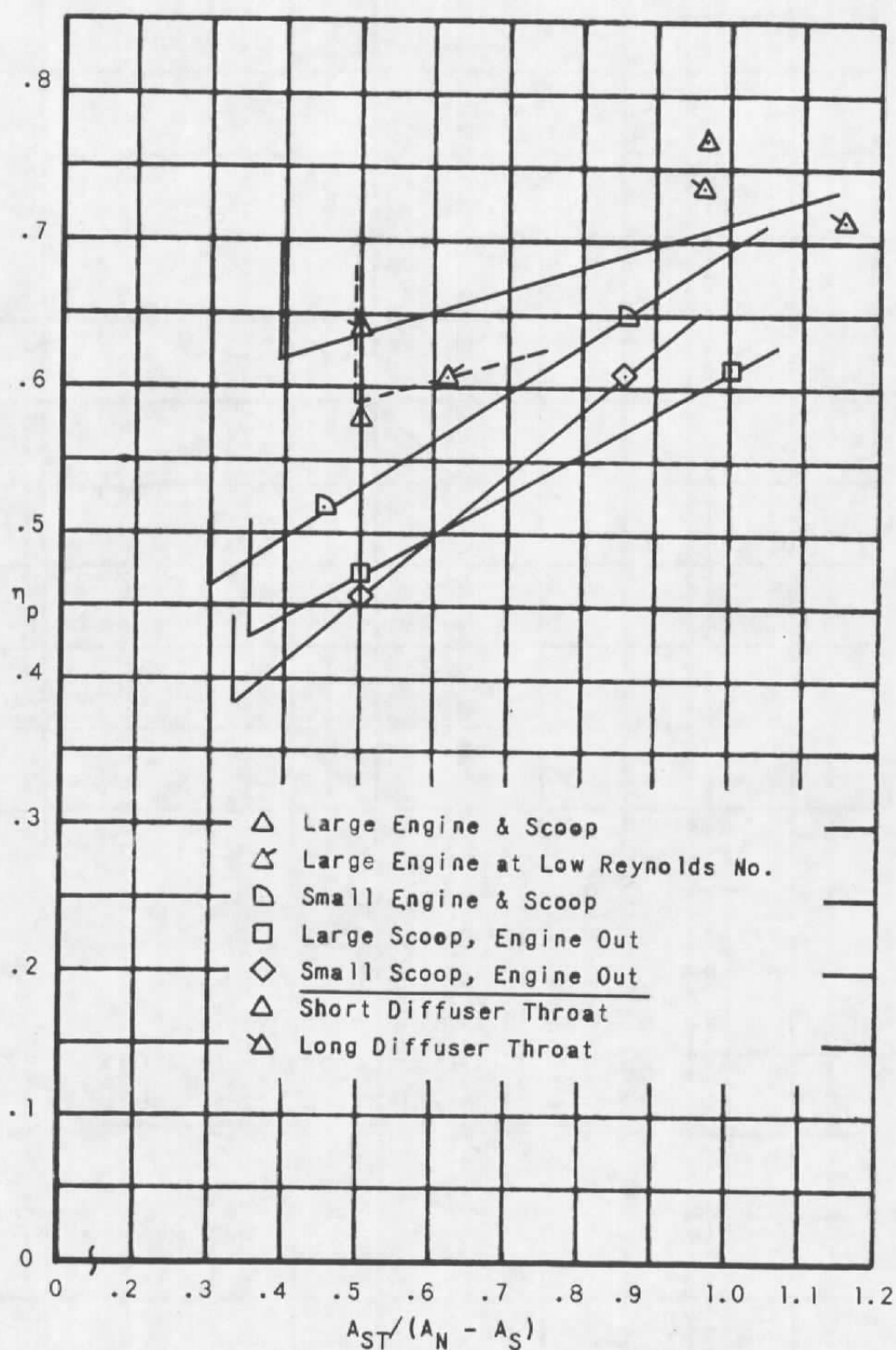


Fig. 11 Diffuser Corrected Efficiency versus Diffuser Throat Setting

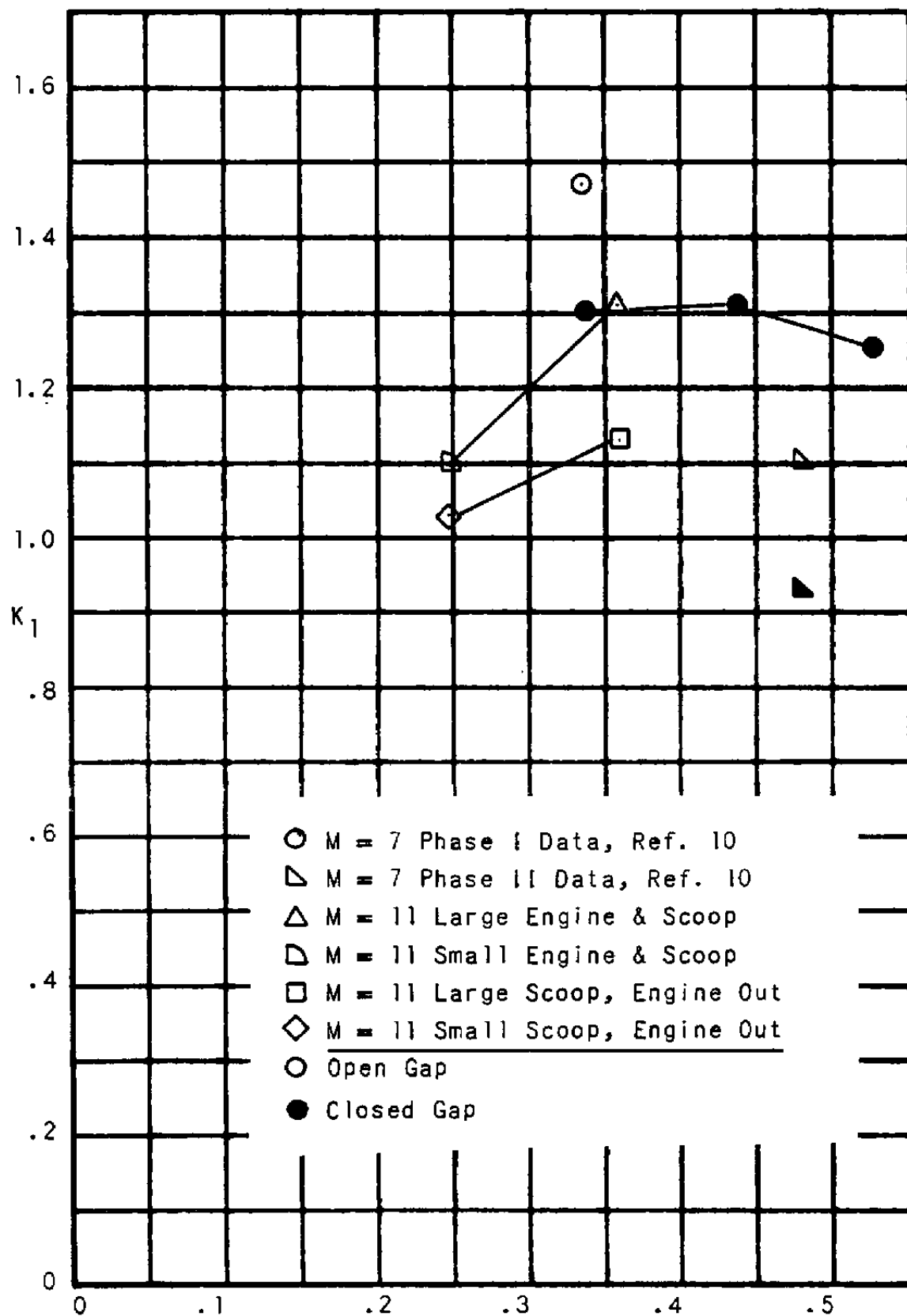


Fig. 12 Minimum Starting Diffuser Throat Area Correlation versus Scavenging Scoop to Nozzle Exit Area Ratio

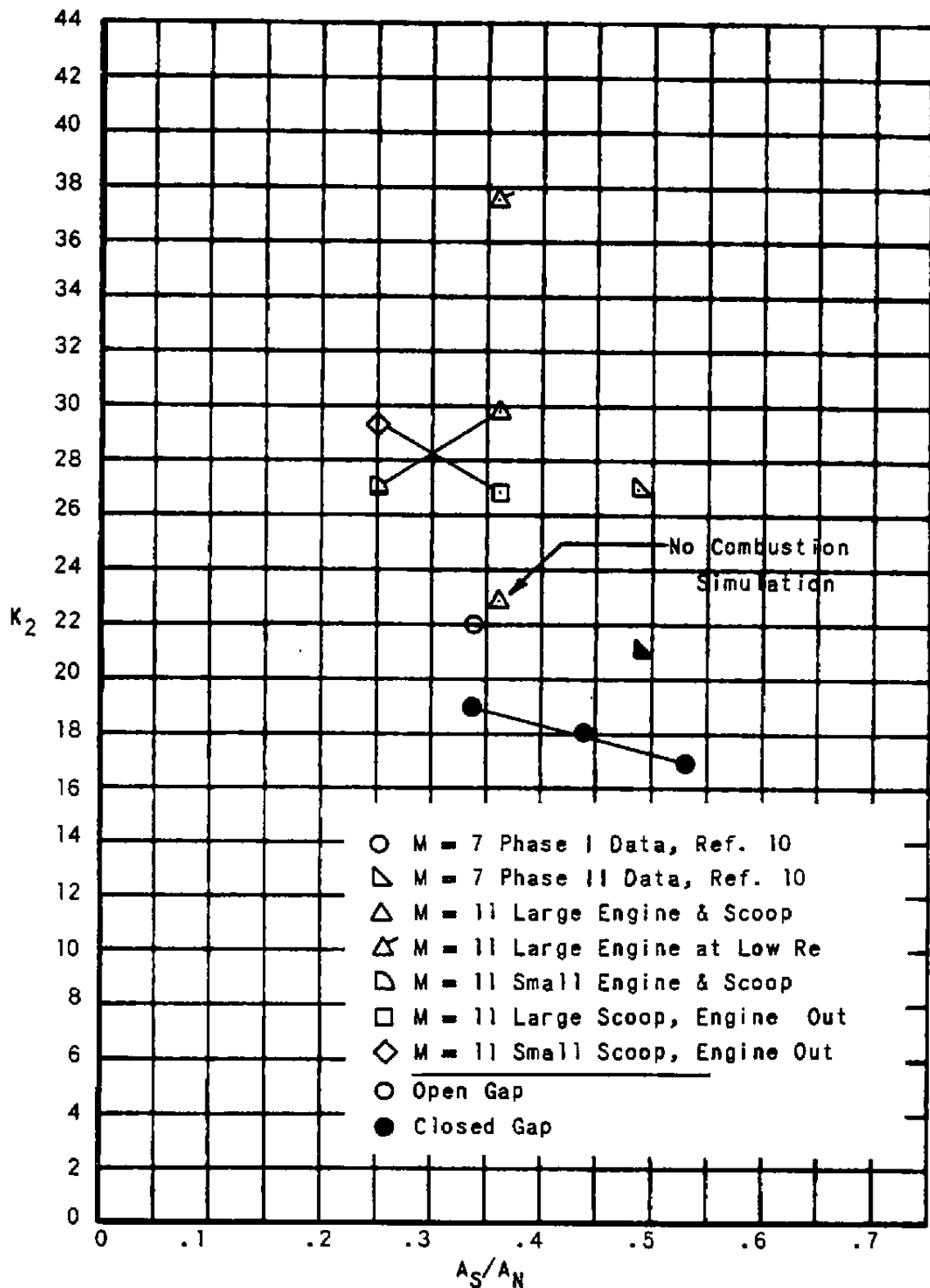
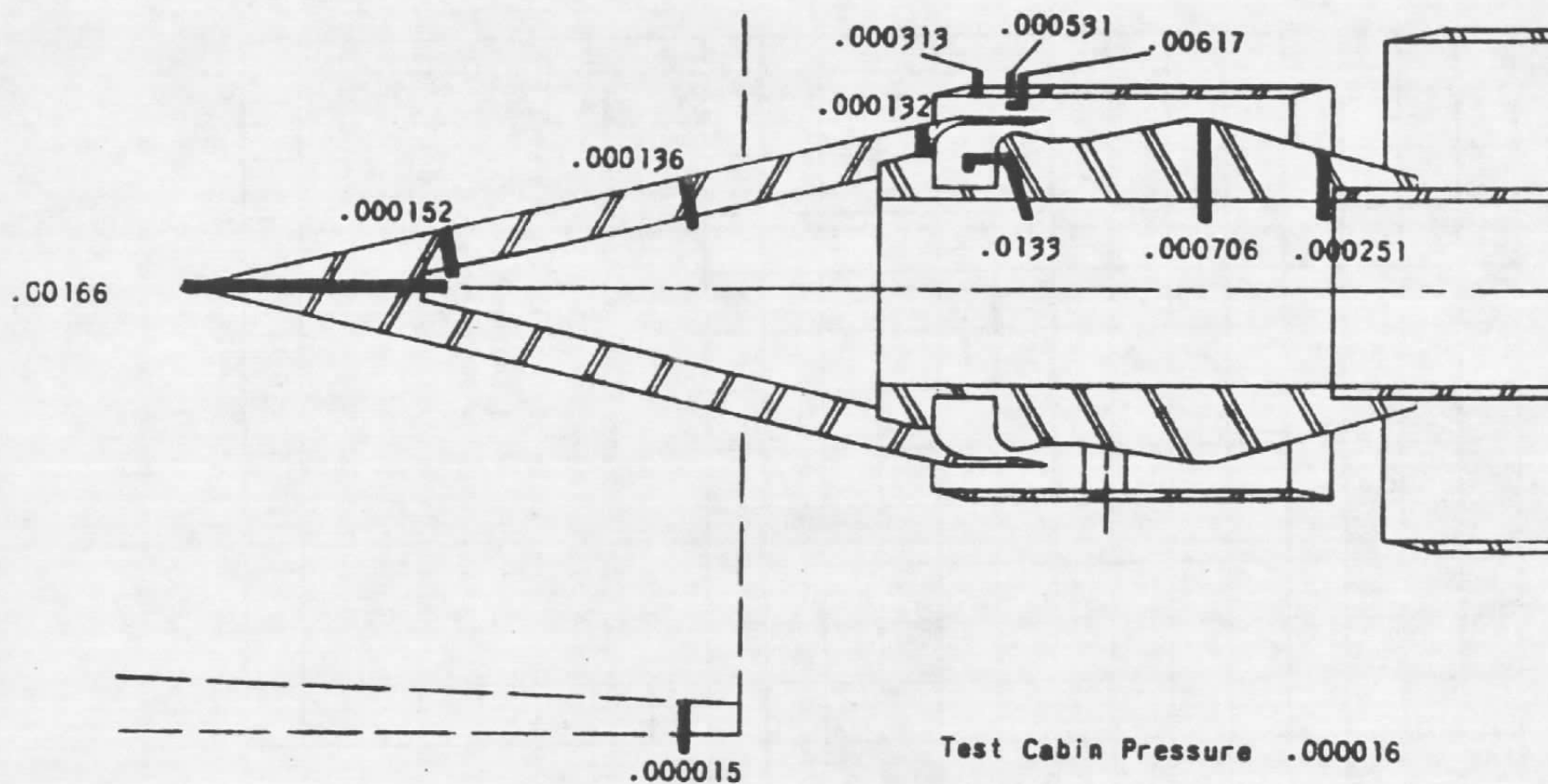


Fig. 13 Minimum Running Diffuser Throat Area Correlation versus Scavenging Scoop to Nozzle Exit Area Ratio



Note: Pressures given as ratio of local pressure to free stream stagnation pressure

Fig. 14 Local Pressures on Engine Model

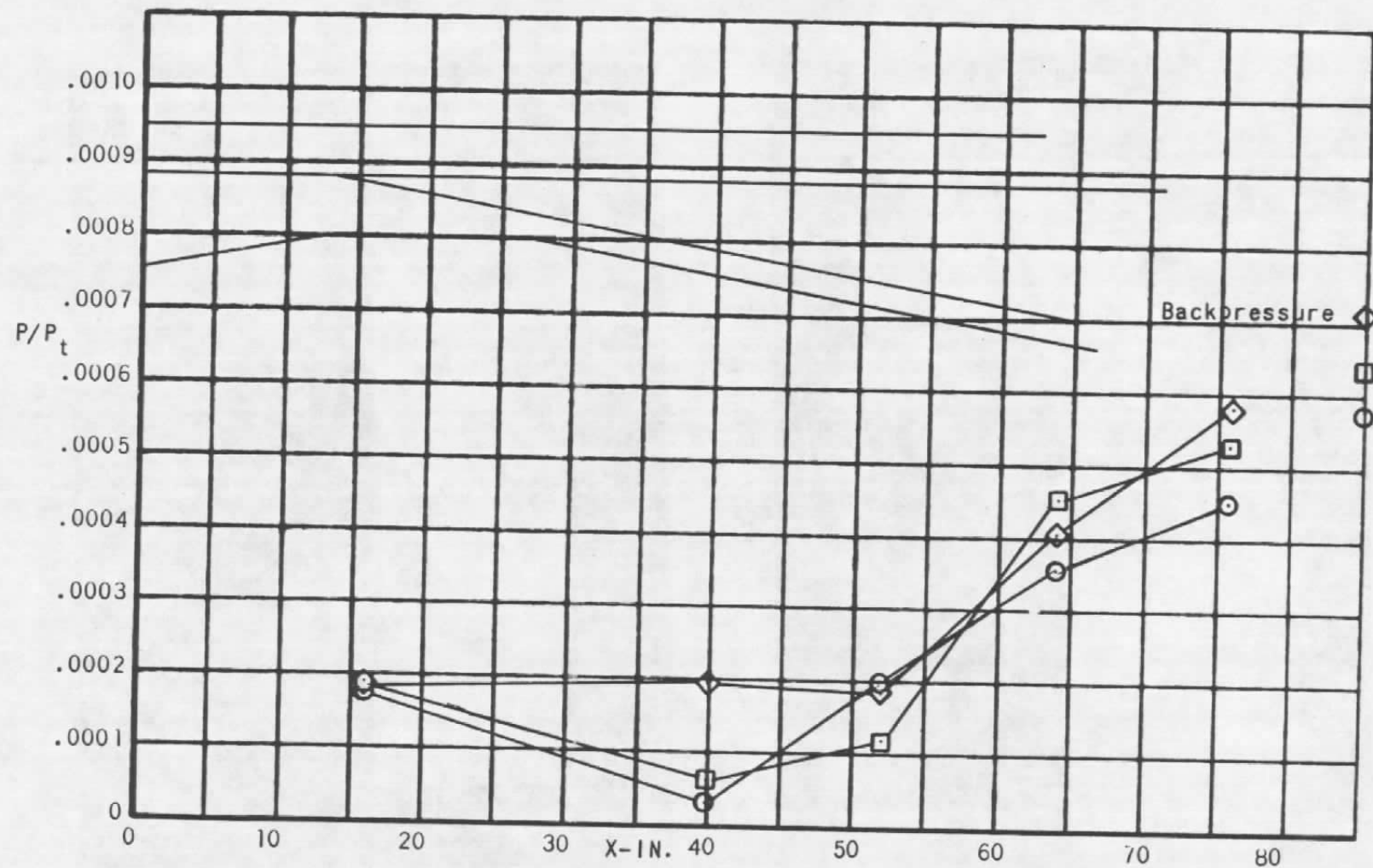
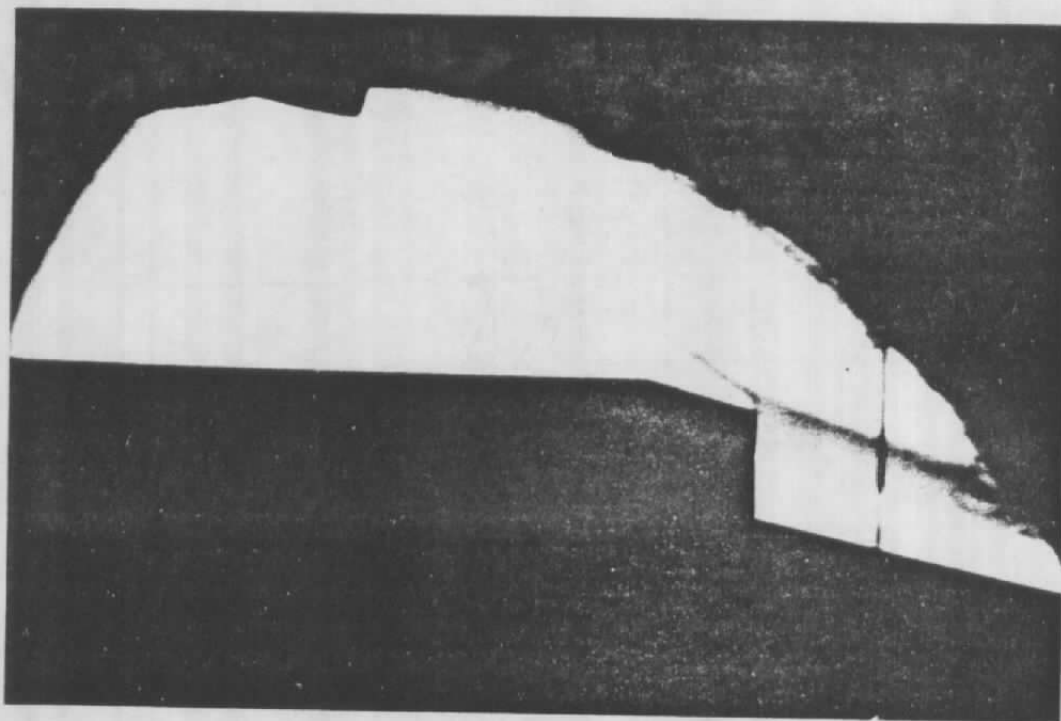
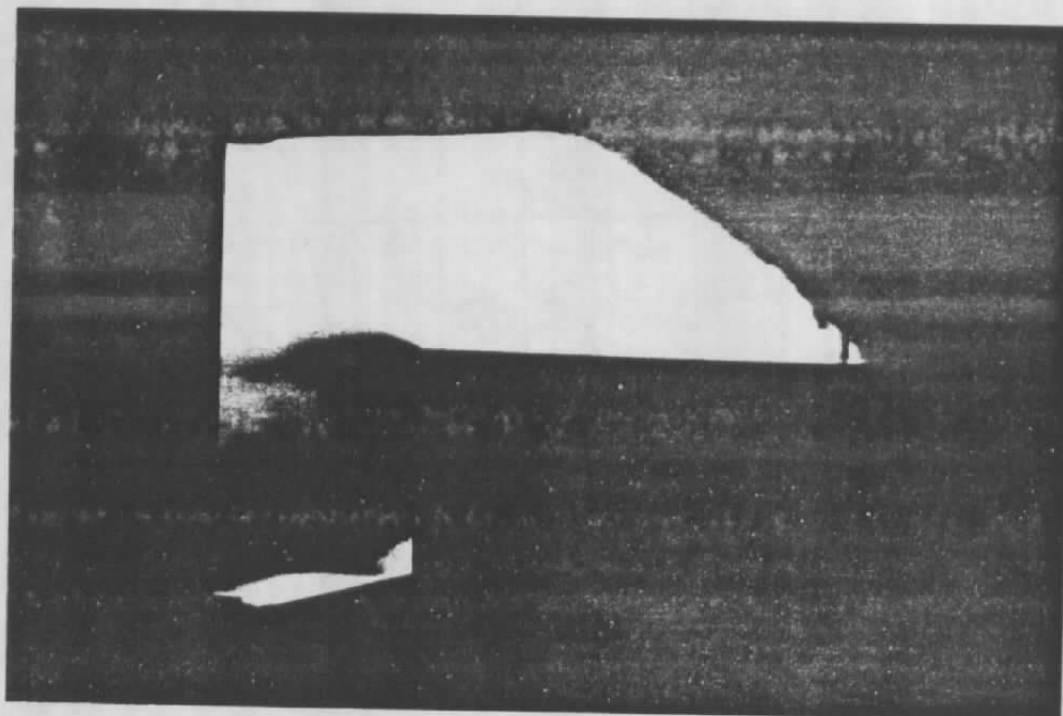


Fig. 15 Bypass Diffuser Pressure Distribution



INLET FLOW FIELD



EXHAUST FLOW FIELD

Fig. 16 Schlieren Flow Photos

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13 ABSTRACT A test program has been conducted to provide ramjet test facility bypass flow second throat diffuser pressure recovery data at a nominal nozzle exit Mach number of 11.0. During the tests, studies were made to determine the effects of Reynolds number, diffuser throat length, inlet capture, area, and other variables. The pressure recoveries obtained during the testing proved to be somewhat better than the original expectations. The peak running pressure recovery was over 60% of free stream normal shock recovery with the adjustable diffuser. Starting pressure recoveries were somewhat lower and ranged mostly from 20% to 30% of normal shock.			

KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
ramjet engines						
second throat diffusers						
test facilities						
bypass flow						
pressure recovery						
hypersonic flow						

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It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as (TS), (S), (C), or (U).

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